Reforming Fisheries: Lessons from a Self-Selected Cooperative*

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Abstract

We analyze a policy experiment in an Alaskan commercial fishery that assigned a portion of an overall catch quota to a voluntary cooperative, with the remainder exploited competitively by those choosing to fish independently. Unlike the individual quota system advocated by many economists, the policy encouraged coordinated fishing and did not require a detailed assignment of rights. We model the decision to join and behavior under cooperative and independent fishing. The data confirm our key predictions: the coop attracted the least skilled fishermen, consolidated and coordinated effort among its most efficient members, and provided shared infrastructure. We estimate that the resulting rent gains were at least 33 percent. Some independents were disadvantaged by the coop's formation, however, prompting them to oppose it in court. We study the source of their disadvantage, and our analysis provides guidance for designing fishery reform that leads to Pareto improvements, enabling reform without losers.

JEL classifications: Q22, D23, L23

1. Introduction

It is widely accepted that the design of property rights plays a key role in determining the value of natural resource stocks. [1] On one end of the property-rights spectrum is 'open access', the regime under which complete dissipation of the stock's value may ensue. On the other end lies 'sole ownership' which provides ideal conditions for maximizing the stock's value. Most of

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[1] Two seminal contributions are Gordon (1954) and Scott (1955).

the world's natural resources are governed by property rights regimes that lie between these extremes.

In the modern regulatory state, with its emphasis on resource management by regulatory agencies, the predominant property rights regime for fisheries is limited entry. Limited entry, which is pervasive in the U.S., Canada, and Europe, caps the number of individuals permitted to fish but fails to assign property rights to the stock. In this system fishermen compete for an administratively determined fishery-wide quota or total allowable catch (TAC). Typically, permit holders are constrained by rules on open seasons, gear types and areas fished. Although the cap on licenses can keep fishermen profits above the open access zero-profit equilibrium, permit holders nevertheless have strong incentives to invest in socially wasteful racing capital.[2] These investments shorten fishing seasons, raise costs and impair the quality and timeliness of harvests relative to what single ownership would induce.

The recent literature on fishery regulation has sought to reform limited entry rights, with the goal of engendering incentives that resemble what a sole owner would face while recognizing that sole ownership is seldom a practical option in the modern regulatory state. Adoption of individual tradable quotas (ITQs), which assign each permit holder a secure share of a fishery's annual TAC, is the reform most commonly advocated by economists. Where ITQs have been adopted, for example in Iceland, New Zealand, Canada and the U.S., the race to fish has moderated and rents have increased. Yet despite these economic successes, as well as clear evidence that ITQ management can facilitate the recovery of 'collapsed' fish stocks, less than two percent of the world's fisheries use systems that assign quantitative catch rights to harvesters.[3] Apparently, implementation of property rights in fisheries and in other mobile natural resources has been hindered by the transactions costs and political obstacles involved in shifting away from

[2] The 'race' and its consequences have been extensively documented in the literature; see Wilen (2005).

[3] For recent empirical evidence on economic successes see Grafton, Squires and Fox (2000), Hannesson (2004), Leal (2002), Linn, Singh and Weninger (2010), Newell, Sanchirico and Kerr (2005). Costello, Gaines and Lynham (2008) present evidence on the reduced probability of collapse for stocks under 'catch share' management regimes, systems that grant some form of quantitative catch rights to harvesters, of which ITQ systems are one variant. The collapse of fisheries is documented in several studies (see Halpern et al. 2008; Myers and Worm 2003; Jackson et al. 2001; Worm et al. 2007). While pollution, climate change, and habitat damage can play important roles, ineffective management strategies are widely believed to be the root cause (Beddington, Agnew and Clark 2007; Hilborn, Orensanz and Parma 2005, Wilen 2005).

an existing regulatory regime.[4] In the fishery, individuals who are well-suited to competing under an existing regime have incentives to block the transition.[5]

Using game theoretical analysis and exploiting a unique fishery management experiment from the Chignik sockeye salmon fishery in Alaska during 2002-2004, we examine an alternative path for fishery reform. This alternative system assigns a secure portion of the aggregate catch to a cooperative group of harvesters, formed voluntarily, to manage as the group decides. Those choosing not to join continue to fish independently under the prior regime and are permitted access to the remainder of the aggregate catch. This novel approach can diminish the incentive to block and at the same time engender incentives that closely resemble what a single firm or 'sole owner' would face. Under conditions we spell out, the transition from limited entry to this alternative regime can be Pareto improving, eliminating opposition to the change.[6]

To fully capture the efficiencies from coordinating input use, the entity that receives the catch allocation must be empowered to manage its members' fishing effort in a unified way, that is, it must be structured as a firm. Managing inputs centrally via contracts with a manager rather than across markets allows an enterprise to capture gains from coordination without incurring excessive transactions costs (Coase 1937).[7] Coordination gains are likely to be important when several inputs shared the use of a single input (Alchian and Demsetz 1972); this clearly is the case in the fishery, where individual harvesters jointly exploit the same stock of fish (Scott 2000). ITQ management will not generally accomplish the coordination needed to optimize the spatial and temporal deployment of fishing effort across an entire fleet (Costello and Deacon 2007).

We contribute to the literature on property-rights reforms by developing a model of this alternative regime and testing its implications with data from the Chignik fishery. Prior to 2002, the Chignik fishery was managed by limited entry and the key policy innovation was to assign a secure portion of the allowed catch to a single entity, the Chignik Coop, to manage as it saw fit. Fishing with the coop was voluntary. Permit holders who joined signed a contract with the coop before the season started and the coop's bylaws empowered it to manage each members' fishing effort. The coop also claimed the resulting profit, which was distributed among members at the

[4] Libecap and Wiggins (1984) and Wiggins and Libecap (1985) show that contracting over common oil reservoirs also suffers from scant implementation due to transactions costs.
[5] See Libecap (2008). Obstacles include contention over the initial allocation of quota among fishermen, and fish processor and local community objections to institutional change. Compounding the problem, inefficient fishery regulation can induce excessive investment in vessels and processing plants. Owners of this capital have incentives to resist regulatory change that would eliminate or impair its value.
[6] The result is 'reform without losers' in the sense of Lau, Qian and Roland (2000) who argue that designing reform to be Pareto improving can minimize political opposition. Participants may still resist change, however, as part of a strategy to obtain a larger share of the gains from reform.
[7] In fact, Coase (1937) refers to the firm's manager as an 'entrepreneur-coordinator'.

end of the season. Given this structure, we model the coop as a profit maximizing organization constrained by a limit on its allowed catch. Permit holders who opted out were free to fish competitively under the pre-existing rules. The regulator accommodated the two sectors by announcing separate fishing times for each. We use this rare circumstance, with the two fishing sectors operating in tandem, to observe the coordination the coop practiced and to measure the resulting efficiency gains. To set the stage, we first place the Chignik experiment in the progression of fishery management institutions and examine how and why this singular institution arose where and when it did.

2. History of the Chignik Coop Experiment

Commercial salmon fishing began in Alaska during the 1870s and was unregulated until 1924 when the White Act imposed catch limits linked to spawning goals.[8] During the latter part of this unregulated phase most of the catch was taken by large stationary fish traps. When Alaska gained statehood in 1959 it immediately banned stationary fish traps despite their acknowledged efficiency, causing employment in the fishery to swell by 6,000 entrants and rents to fall.[9] The resulting regime was essentially open access, but with a limitation on the gear allowed.

In 1973 Alaska adopted the limited entry system that is still used today in most of Alaska's fisheries. Under limited entry, the number of licenses is fixed and individual license holders compete for a fishery-wide catch limit set by regulators. A political motive for fixing the number of licenses was to prevent entry by fishermen from Washington State and elsewhere, where fishing opportunities were being eroded by court decisions and declining stocks.[10] Alaskan limited entry licenses are transferrable and positive license prices indicate that rents were generated. Fish ownership was still governed by the rule of capture, however, encouraging fishermen to compete in an inefficient race to harvest a share of the allowed catch before competitors. It is well established that these racing behaviors dissipate rents.[11]

Although ITQs are now used in several important Alaskan fisheries, they have not been implemented for salmon either in Alaska or to our knowledge elsewhere. This dearth of implementation arguably has several causes. Presumably, the political obstacles that have so

[8] See Colt (1999) and Crutchfield and Pontecorvo (1969).
[9] According to Colt (1999), the rent reduction was equivalent to 12% of the exvessel price.
[10] For example, the 1974 court decision in *U.S. vs. Washington* 1974 decreased by 50 percent the salmon allocation to fishermen who weren't members of Native American tribes (Nickerson, Parker and Rucker 2010).
[11] Wilen (2005).

severely limited ITQ implementation elsewhere have worked to hinder implementation for salmon as well. Further, due to the migratory nature of salmon and the pulse nature of salmon runs, complete rent capture requires extensive coordination on the spatial and temporal deployment of effort and on public input provision. Our model outlines this argument in more detail. ITQs alone fail to accomplish these tasks, and thus will forego these potential gains unless individual quota owners can collectively agree to coordinate their actions (Costello and Deacon 2007).[12]

Chignik (see Fig. 1) is one of Alaska's oldest and most important commercial salmon fisheries. The gear used is the purse seine, a large net deployed in the water like a curtain and then cinched from the bottom to prevent fish from escaping when the net is hauled.

Sockeye salmon migrate towards only one river in the Chignik system, Chignik River, and are "funneled" into relatively dense concentrations as the migration proceeds from open ocean, through Chignik Bay, into Chignik Lagoon, and finally into Chignik River (see Fig. 2). Processing facilities are located and purse seine vessels are moored near the final destination.[13]

In 2002 the Alaska Board of Fisheries approved a request by a group of Chignik permit holders to form annual cooperatives for voluntary joiners; this arrangement continued through 2004. The number of fishermen who joined ranged from 77 in 2002 and 2003 to 87 in 2004, with the total number of permits equaling 100 throughout the period. Each year the coop was allocated a share of the total allowable catch (TAC) to harvest as it saw fit, with the remainder designated for traditional, competitive harvest by the independent sector. The two sectors fished at different times, determined by the regulator, and each sector's season was closed when its TAC share was reached. The coop's TAC share in a given year was determined by the following rule: (i) if less than 85 percent of permit holders joined, the coop received an allocation equal to nine-tenths of a per capita share for each joiner; and (ii) if 85 percent or more of permit holders joined, the co-op received a full per capita share for each joiner. This rule allocated 69.3 percent of the TAC to the coop in 2002 and 2003 and 87 percent to the coop in 2004. When the coop was shut down by an Alaska court ruling in 2005, the regime reverted to the pre-coop system with competitive fishing for all 100 permit holders.

[12] Other authors have identified potential efficiency advantages for user-based organizations that coordinate the activities of individual members. Scott (1993, 2000), for example, relies on this basic reasoning in arguing that fishery governance by harvester-based organizations represents a logical next step—beyond ITQ regulation—in the development of fishery management. Sullivan (2000) discusses transaction-cost and enforcement advantages that harvester cooperatives may have over ITQ policies, but concludes that harvester coops may be less durable than ITQ systems because they exist at the pleasure of their members.
[13] A more detailed map of the area can be found at: www.mapquest.com/maps?city=Chignik Lake&state=AK.

This history motivates several questions. First, why did the coop form, and why at Chignik? One plausible reason is that Chignik fishermen had prior experience with the benefits of cooperative management because of a 1991 strike aimed at securing higher prices from local processors. During the strike the Chignik Seiners Association (CSA), a lobbying organization for local fishermen, negotiated an agreement in which local fishermen rotated efforts to bring pre-determined volumes of catch to alternative processors who offered higher prices. Experience with this rotational scheme convinced participating fishermen that effort coordination could yield much higher catch per unit effort than conventional fishing (Knapp 2007).[14]

Second, what accounts for the time lag between the promising 1991 experience with coordinated fishing and the coop's eventual launch in 2002? Plausible reasons for the delay include the questionable legality of a cooperative under Alaskan law, hesitance by some fishermen to join a cooperative and disagreement over how any catch quota granted to the coop would be divided among members.[15] The launch in 2002 was evidently precipitated by a second strike against processors in 2001 which once again demonstrated the advantages of coordination and consolidation.

Third, how did the coop policy affect fishing practices and the level and distribution of rents, and why was it dismantled after only 3 years? We address these questions in detail in the remainder of the paper. Given the coop's contractual structure we model it as an organization motivated to maximize profit subject to a catch limit. We model the independent sector as a group of independent harvesters participating in a noncooperative game. Because fishing with the coop was voluntary, our model allows for heterogeneous skills and examines the decision to join the coop or fish independently. This leads to empirical predictions on how different skill levels will sort between the two sectors, and to subsequent empirical tests. Finally, our model considers the question of whether the with-coop equilibrium represented a Pareto improvement over the equilibrium in which all participants competed in limited entry fishing. This leads to a close examination of the rule used to allocate the allowed catch between sectors and a discussion of the Alaska Supreme Court decision that overturned the coop. The model's presentation in the text stresses intuition; proofs and detailed derivations appear in the Appendix.

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[14] As McCallum (1997) explains, strike participants found that the most cost effective fishing method involved the use guiding barriers to direct salmon within Chignik lagoon. This reduced the number of seiners required to harvest the allowed catch and saved on transportation costs by concentrating effort near processing sites. The strike also demonstrated the economic advantages of bargaining collectively with processors over price.

[15] A 1997 letter from the CSA Director documents continuing concern with the allocation question (McCallum 1997).

3. Model

Our model is structured to highlight possibilities for coordinating the actions of inputs that share the use of a single resource, a stock of fish in this case.[16] This consideration is introduced in two ways. First, it is well-known that harvesting efficiency can be enhanced by coordinating the spatial deployment of fishing effort if the unit value of the stock varies over space.[17] In Chignik, cost per unit effort declines as the stock migrates toward a port where fishing vessels and processing facilities are based. A single firm coordinating the effort of all harvesters will rationally intercept the stock at the most advantageous location, typically near the port. Independent fishermen have an incentive to intercept the stock before rivals do, however, in order to exploit an unfished stock, and this can result in excessive costs. Our model incorporates this coordination problem by dividing the fishing grounds into two zones, regarding the distance to each as a single value, 0 or $\bar{d}$, and specifying that fishing at the greater distance raises the cost per unit effort. We refer to these zones as 'inside' and 'outside', respectively, and compare the coop's choice of fishing location to the equilibrium locations of independent fishermen.

Second, gains can be achieved by coordination in the provision and use of non-rival public inputs. Fishery-related examples include shared information on stock locations and shared harvesting infrastructure (up to the point of congestion). A standard free-rider argument indicates that public inputs will be under-provided by independent agents contributing to their provision.[18] Efficiency in public input provision can be promoted, however, by placing the agents who use them under the direction of a single manager empowered to claim the resulting net revenue. Our model includes a non-rival public input, G, that reduces the cost per unit effort. We assume the public input is available only to harvesters in the sector that provides it.[19]

These two opportunities for coordination are assumed to affect the cost per unit effort. Effort, in turn, is represented by the product of time spent fishing, T, and an individual skill parameter, γ, interpreted as the rate at which the individual can apply fishing effort. This specification implies that effort can be managed by controlling time spent fishing, which agrees

[16] Coase (1937), Alchian and Demsetz (1972), Scott (1955).
[17] See Costello and Deacon (2007).
[18] If individuals are unwilling to share information on stock locations with other fishermen, effectively underproviding public information, the result could be excessive or redundant search in the aggregate, because locations searched and found to be unproductive by one individual might be repeatedly searched by others (Costello and Deacon 2007).
[19] Because the two sectors fish at different times in the Chignik case, this is an assumption that shared inputs are not permanent or durable. This applies to the key public inputs the Chignik coop provided: day to day information on stock densities and removable infrastructure.

with the way effort was managed in the fishery we study. Letting the subscript h refer to an individual fisherman, the individual's total cost is

$$c_h = \{\alpha + d_h - G(\sum_i x_i)\}\gamma_h T_h + \phi_h T_h + x_h \,. \qquad (1)$$

The expression in brackets incorporates all cost components that are proportional to h's effort. We include a common cost parameter, α, and measure distance, d_h, in units of cost. The term x_h is h's contribution to the public input and $G(\sum_i x_i)$ is the amount of public input provided by h's sector. We assume $G(0)=0$, $G'>0$, $G''<0$ and $\alpha + d_h - G(\cdot) > 0 \; \forall h$. We also include the opportunity cost of h's time spent fishing, $\phi_h T_h$. If h has an attractive opportunity in another fishery that operates at the same time or in an entirely different occupation, ϕ_h will be large.

Total catch, Q, is linked to aggregate effort, E, and the stock, Z, by a linearly homogeneous fishing technology,

$$Q = ZF(E/Z) \qquad (2)$$

where $F'>0$, $F''<0$, $F(0)=0$ and $F(E/Z)<1$. The regulator imposes a biologically determined catch limit, expressed in what follows as a fraction of the stock $Q \le \beta Z$. This catch constraint implies an upper limit on effort, $E \le ZF^{-1}(\beta)$. Each season's allowed catch and the available stock are determined by the regulator's current and prior year actions. These terms are fixed from the industry's point of view, so we treat them as parameters in what follows and focus on within-season fishing activities.[20]

In the fishery we study the stock's migratory behavior enabled the regulator to divide the catch in such a way that one sector's catch did not interfere with the fishing opportunities of the other. Salmon predictably migrate through the fishing grounds toward their spawning stream during a known part of the year. Each sector was allowed to fish during a separate part of this

[20] A firm assigned a secure catch quota could in principle choose to harvest less than what the regulator allows in a given year in order to increase future stocks, in which case its total catch would be a choice variable rather than a fixed quantity. We regard this possibility as remote in the case we study, and ignore it in what follows. We have two main reasons for this choice. First, if one sector reduced its harvest to generate a higher return in the future, part of that future return would be captured by the other sector and thus be external to the sector making the sacrifice. Second, biologically determined catch limits imposed by regulators often are lower than what a profit maximizing manager would choose.

migration period.[21] The portion of the annual run arriving during the independent sector's open season was a stock available to that sector alone. Once the independent's season closed, the uncaught portion of its stock escaped up river. The same process could then be implemented for the cooperative sector, by opening its season for a period of time and effectively dedicating a portion of the annual run to the cooperative.[22] We denote the independent and cooperative groups by *I* and *J*, respectively, their assigned stocks by Z_I and Z_J and the numbers of harvesters in each group by *n*(*I*) and *n*(*J*). We specify that the run was partitioned in proportion to the number of permit holders in each group, that is, $Z_J = Z\, n(J)/n(K)$ for group *J*, where *n*(*K*) is the total number of harvesters in both groups. We later relax this allocation rule.

The independent sector's total effort is $\sum_{h\in I} \gamma_h T_h$. The regulator can ensure this sector meets its catch limit by closing the independents' fishing season after T_I periods, where

$$\sum_{h\in I} \gamma_h T_I = Z_I F^{-1}(\beta)\,. \tag{3}$$

The cooperative faces a similar catch limit, but is free to meet it by choosing distinct fishing times for individual members. In addition, the cooperative's fishing times logically cannot exceed duration of the salmon run minus the length of the independent sector's season. We express this upper limit by $\overline{T}$.

It remains to specify how the location of fishing affects catch. To simplify we treat the stock available to a given sector as a dimensionless mass, *Z*, which moves along a migration route. Given the harvest technology, applying E_T units of effort to this stock will yield a catch of $ZF(E_T/Z)$. If this effort is applied sequentially, with E_0 units applied first and $E_T - E_0$ units subsequently, the first 'batch' of effort yields a catch of $ZF(E_0/Z)$ and the second yields a residual catch of $Z(F(E_T/Z) - F(E_0/Z))$. Concavity of $F(\cdot)$ implies that catch per unit effort for the first application of effort is greater than for the second. Because the stock's migration route takes it toward port, the first batch of effort is necessarily applied farther from port than the

[21] We treat the regulator's choice of TAC as exogenous, independent of the behavior or composition of the two sectors. This assumption is appropriate for Chignik and other Alaska salmon fisheries, as explained in Section 4.1

[22] For a sedentary species that does not redistribute itself over the fishing grounds as fishing proceeds, a similar stock division could be achieved on a spatial basis by allocating portions of its habitat to each sector. A spatial division would not work if the target stock redistributes while fishing occurs because harvests by one sector would subtract from the stock available to the other, setting off a race to fish.

second. Consequently, catch per unit effort is higher for those who fish outside than for those who fish inside.[23] This creates an incentive for the independent fisherman to fish at a distance. Offsetting this is the fact that fishing at a greater distance increases cost per unit effort.

There are two kinds of decisions to examine, the initial joining decision and subsequent decisions on effort deployment. We model these as a two-stage entry game and identify subgame perfect Nash equilibria by backward induction.[24]

3.1. Effort deployment by the coop

Because total catch is fixed by the regulator, profit can be maximized by solving the following cost minimization problem:

$$\min_{d_i, T_i \; i\in J; x_J} \sum_{i\in J} \left(\alpha + d_i - G(x_J)\right)\gamma_i T_i + \sum_{i\in J} \phi_i T_i + x_J , \qquad (4)$$

$$\text{s.t. } \sum_{i\in J} \gamma_i T_i = Z_J F^{-1}(\beta),\ d_i \in \{0, \overline{d}\} \text{ and } T_i \in [0, \overline{T}] \text{ for all } i \in J ,$$

where x_J is the coop's expenditure on the public input.

The profit maximizing policy is straightforward.[25] First, it sets $d_i = 0$ for each member that spends positive time fishing. This is obvious because (4) is non-decreasing in $d_i T_i,\ \forall i \in J$. Second, public input provision satisfies a Samuelson condition for optimal public good provision; for an interior solution this is $G'(x_J)F^{-1}(\beta)Z_J = 1$. Both results reflect the gain from solving coordination problems. Third, the profit maximizing policy assigns positive harvest times to a subset of members who have the lowest values of the ratio ϕ_i/γ_i and limits the number of members who fish so that these efficient members fish as long as possible, $\overline{T}$ periods. Other members do not fish at all (but still share in the coop's profits). Concentrating effort among this group is intuitive because ϕ_i and γ_i are *i*'s cost per unit time and effort per unit time, respectively, so the ratio ϕ_i/γ_i is *i*'s cost per unit effort. Slowing the rate of fishing to extend the season concentrates effort among these efficient harvesters to the greatest extent possible.

These results are summarized as follows:

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[23] Costello and Deacon (2007) apply similar reasoning to harvesting of a non-migratory stock that inhabits patches at varying distances from port.

[24] Consistent with positive permit values in the fishery examined, we assume each firm is capable of earning positive profit by fishing independently, regardless of the composition of the independent and coop fleets.

[25] Because any coop member could have earned positive profit from fishing as an independent, the coop's maximal profit is necessarily positive.

Proposition 1 The cooperative's profit maximizing policy requires that:

(i) All active members fish as close to port as possible;

(ii) Provision of the public input equates the coop's marginal benefit from provision to marginal cost, satisfying a Samuelson condition;

(iii) Fishing is restricted to members who have the lowest cost per unit effort $\left(\phi_i / \gamma_i\right)$ and effort is slowed to allow fishing to continue for as long as possible, $\overline{T}$ periods.

As a means of comparison, it is worth noting what would be the profit maximizing behavior of a social planner who is unconstrained by the institutional structure on which this paper focuses. It is straightforward to show[26] that the planner adopts precisely the same set of actions as are outlined in Proposition 1.[27] In other words, the profit maximizing solution is equivalent to the solution achieved by a cooperative of size $n(J) = n(K)$ and an independent group of size $n(I) = 0$.[28]

3.2. Stage 2 choices by independents

Fishermen choosing to fish independently face a set of decisions similar to that of the coop manager. In this case, each fisherman must independently decide how much time to spend fishing, how much to contribute to the public good and where to fish. Because profit is linear and increasing in time spent fishing, each independent will fish the entire season. Recognizing this fact the regulator must set the season length to meet the desired catch (see Equation 3). The highest skill fisherman is the only fisherman who might be motivated to contribute to the public good, thus it is insufficiently provided by the independent fleet.

Finally, we find that the equilibrium fishing location choices of independent fleet members depend on a complex interplay of model parameters. The tradeoff involved has a straightforward intuition, however. Fishing outside is costly, but it enables an individual to contact the stock before all those who fish inside and consequently obtain a higher catch per unit effort. If the cost per unit effort of fishing outside is relatively low, all fishermen will fish outside in equilibrium and nobody will find it in his best interest to save on costs by deviating inside. On

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[26] The social planner faces the minimization problem given in Equation 4, replacing *J* with the set of all fishermen in the fishery.

[27] To make Proposition 1 relevant for a social planner, simply strike the word "cooperative" and replace the word "members" with the word "fishermen."

[28] We do not explicitly consider coordination or contracting costs within the cooperative. An explicit treatment of this would reveal an additional tension, possibly reducing the socially optimal cooperative size.

the other hand, if the cost per unit effort of deviating outside is very high, it is in all fishermen's best interest to fish inside; in this case the benefit of intercepting the stock earlier never outweighs the high cost of fishing outside. Intermediate cases, where some fishermen fish inside and some fish outside, can also be equilibria for intermediate values of the 'distance' cost. This decision calculus is based on our model's predictions of the consequences of deviating in location, derived from the average and marginal catch per unit effort; see Appendix. These results are summarized below.

Proposition 2 In the subgame involving the independent sector's choice of time spent fishing, public input contributions, and fishing locations, a Nash equilibrium strategy profile requires that:

(i) Each independent harvester fishes the entire time the regulator leaves the independents' season open;

(ii) The independent sector under-provides the public input relative to what is efficient;

(iii) For sufficiently low cost of fishing at the outside location (relative to the gain in catch per unit effort) some or all independents will choose to fish at the inefficient outside location.

We also note that the TAC constraint (3) and the regulator's stock assignment, $Z_I = Z\, n(I)/n(K)$, imply that the independent sector's season length equals

$$T_I = \frac{ZF^{-1}(\beta)/n(K)}{\sum_{i \in I} \gamma_i / n(I)}. \tag{5}$$

It is therefore inversely proportional to the group's average skill, a result that will become useful later.

3.3. *The Stage 1 decision of whether or not to join*

Having determined equilibrium behavior of the two fleets (independent and cooperative), we now turn to the stage 1 decision of which fleet to join. We adopt the convention that fishermen are indexed in increasing order of their γ terms, so low skill fishermen have low index numbers. To obtain a clear identification on the attributes of coop joiners, we assume that high skill harvesters (high γ) have low cost per unit effort (low ϕ/γ). This will be true if the ϕ terms are constant, if ϕ and γ are inversely ordered, or if ϕ does not increase more than proportionately as γ increases.

We start by examining the second stage profit shares of successive coops in which new members are added in order of their γ parameters. In the Appendix we focus on the marginal skill fisherman and his motivation to join (and thus contribute to) an existing cooperative, or to fish independently. Figure 3 illustrates our analysis and identifies the equilibrium cooperative size, independent fleet size, and the skill composition of members in each sector. The vertical axis is the profit per member. The horizontal axis is the size of the cooperative (from 1 to all fishermen, *n(K)*), ordered by skill, γ. We first show the intuitive result that, when new members are added in order of increasing skill, coop profit per member increases monotonically with coop size. The upward sloping solid line $\pi_C(\gamma)$ shows the profit per member of the cooperative for successively larger size cooperatives (formed by accumulating additional members with greater skill).[29] The left intercept of this curve corresponds to the profit of a 'single person cooperative'; while this case strains the definition of a cooperative, it really just represents a secure catch allocation and separate fishing period for the lowest skill fisherman in an amount that equals a per capita share of the entire TAC. This intercept is positive for two reasons: (i) by assumption, all fishermen could earn positive profit by fishing independently, and (ii) the per capita catch allocation exceeds what this (least skilled) harvester would catch as an independent. The same reasoning also implies that the single person coop's profit exceeds what the same lowest skill fisherman could earn by fishing independently with all other harvesters; this result is useful shortly.

Next we examine the marginal profit from independent fishing for independent fleets composed of successively lower skilled fishermen. This is illustrated by the dashed line $\pi_m(\gamma)$ in Fig. 3. When read from right to left this line indicates that as successively lower skill fishermen are added to the independent fleet, the lowest skill individual's profit monotonically declines. The left intercept of this curve necessarily lies below the solid curve that shows profit per coop member, as was just explained. If the right intercept lies above the solid curve, then the two must cross at least once in which case there is at least one equilibrium in which some harvesters join the coop and some fish independently. Fig. 3 illustrates this possibility. Fishermen with skill levels between 1 and *e* earn more by joining the coop than by fishing independently, and the reverse is true for all fishermen with skill levels between *e*+1 and *n(K*). Skill level *e* thus corresponds to the marginal, or highest skill, coop joiner; skill level *e*+1 corresponds to the lowest skill non-joiner. The crossing point for the two curves determines both the equilibrium

[29] This solid line is a smooth curve connecting a set of discrete points indicating the per member profits for coops of different sizes.

cooperative size and the allocation of skills. If the solid line lies everywhere below the dashed line, all fishermen choose to join the coop.

These results are summarized as follows:

Proposition 3 Under our assumption on the relationship between effort rate and time cost parameters, a subgame perfect Nash equilibrium strategy profile satisfies the conditions in Propositions 1 and 2 and in addition has the following property:

The group choosing to fish independently consists of highliners; more precisely, all independents have skill levels greater than any coop member.

3.4. Characterizing Pareto-improving catch allocations

The above discussion characterizes the membership and economic behavior of heterogeneous fishermen composing the two fleets. Here we focus on whether all fishermen are likely to support the formation of the cooperative. In particular, we examine whether allowing formation of the self-selected cooperative can be Pareto improving.

The answer hinges on the allocation of catch between the two sectors. We have assumed thus far that the regulator assigns catch in proportion to membership: $Z_J = Z\, n(J)/n(K)$. To explore this issue more completely, we generalize the allocation formula to allow for disproportionate assignments: $Z_J = Z\, \theta n(J)/n(K)$ where the scalar θ controls the proportional assignment to the cooperative sector. For example, if θ=0.9 then the cooperative is assigned a stock allocation that provides nine-tenths of a per capita share for each coop joiner. Intuitively, it would seem that cooperative members would be advantaged and independents disadvantaged by larger values of θ, but the endogeneity of self-selected membership may blur this intuition. We start by deriving the profit for an arbitrary fisherman, *h*, in a 'completely independent fishery', a term we use to refer to the counterfactual situation where no coop is allowed to form. We then compare this profit to what *h* would earn when the cooperative is allowed to form. Naturally, we must simultaneously solve for whether fisherman *h* fishes independently or as a member of the cooperative fleet, and for the associated season length and fishing locations in equilibrium; these choices will depend on θ.

We characterize our results relative to the benchmark allocation value, θ_c, at which each independent is equally well off whether or not the cooperative is allowed to form. Our earlier results (that the joiners are relatively less skilled and the independents more skilled) allow us to show that $\theta_c < 1$. When the cooperative receives a larger allocation (given by some $\theta > \theta_c$)

independents are made worse off (indeed, so are the more productive cooperative members), so this cannot be Pareto improving. On the other hand, if the coop's allocation is too low (given by some $\theta < \theta_L$) the incentive to join the cooperative is insufficient for any cooperative to form at all. But, we find that for intermediate values of θ fishermen of all skill levels (joiners and independents alike) are all advantaged by the ability of the cooperative to form. These striking results are summarized below.

Proposition 4 The formation of a self-selected cooperative has the following distributional consequences:

(i) If $\theta_L \leq \theta \leq \theta_c$ the institutional design is Pareto improving – fishermen of all skill levels are made weakly better off by allowing the cooperative to form.

(ii) If $\theta > \theta_c$ the institutional design is not Pareto improving – all would-be independents and some would-be cooperative fishermen are made worse off by allowing the cooperative to form.

(iii) If $\theta < \theta_L$ then no cooperative forms.

These results are established in the Appendix.

4. Empirical Evidence

We employ a mix of quantitative and qualitative data to test the theory and to analyze related effects of the coop policy at Chignik. We compare fishery-wide outcomes in the Chignik fishery during three distinct time periods: before the coop (pre-2002), during the coop years (2002-2004), and after the coop was shut down (post-2004).[30] We also compare outcomes in the Chignik fishery to outcomes in Alaska's other purse seine fisheries, all of which fished competitively with a TAC limit. Finally, we compare the behavior of Chignik permit holders who fished for the coop to the behavior of Chignik independents.

After summarizing the quantitative data, we present the evidence in four subsections that roughly follow the sequence of decision making at the Chignik Fishery. The first subsection

[30] The availability of data over three distinct time periods (before, during, and after the coop) helps us isolate the casual effects of the cooperative from fishery specific time trends (Meyer 1995, p. 158). The three distinct periods also helps eliminate serial correlation in our panel regression models (Bertrand, Duflo and Mullainathan 2004, p. 251).

focuses on the decision to join the coop. It tests the proposition that highliners will remain independent while less-skilled fishermen will opt into the coop (Prop.3) using data on the catch share histories of fishermen prior to 2002 to measure relative skill. The second subsection compares the consolidation and coordination decisions of the coop and the independents. It begins by testing the proposition that the coop will consolidate effort among its most skilled members and that this will necessarily lengthen fishing seasons (prop.1.iii) using data on catch share histories to measure relative skill and data on the number of active licenses and days fished to measure consolidation and season length. We test the proposition that the coop will fish closer to port than will the independents (prop.1.i and prop.2.iii) using spatial data on fish caught in "inside" and "outside" zones. We conclude the subsection by testing the proposition that the coop will contribute more towards public inputs when compared to independent fishermen (prop.1.ii and prop.2.ii) using qualitative comparisons of infrastructure provision and the coordination of fishing effort. The third subsection examines the effects of the coop policy on ex-vessel prices of salmon and on license values. The final subsection assesses the proposition that coop stability requires that it be Pareto improving for joiners and independents (prop.4) using data on the historic catch of coop joiners and independents, the regulator's TAC allocation rule and the timing of the lawsuit challenging the coop.

4.1. Data description

To test the predictions that coop joiners will be less skilled fishermen than non-joiners, and that the most skilled coop members will actively fish on behalf of the coop, we use data on the catch-share history of fishermen during the pre-coop period to proxy fisherman skill. Although individual catch shares are not disclosed due Alaska confidentiality laws, we were able to obtain catch share data that are aggregated to groups of three fishermen.[31] The procedure for carrying out these aggregations was designed to minimize catch share heterogeneity among the observations that were grouped. Because some harvesters changed status during the coop period, different aggregations were formed, using the same procedure, for 2002, 2003 and 2004. For 2002 aggregations, individual fishermen were first partitioned into three groups depending on their 2002 coop status: coop joiners who fished, non-fishing coop joiners and independents. All fishermen in a given group were ordered by average sockeye catch share over the historic 1995-2001 period.[32] Successive fishermen were then clustered into groups of three and the average

[31] We are indebted to the Alaska Commercial Fisheries Entry Commission for performing these aggregations for us. In a few cases it was necessary to aggregate over four firms.

[32] We do not consider more distant catch histories because vessel attributes and skill levels can change over time; we do not consider other salmon species because the coop fished exclusively for sockeye.

historic catch share within each cluster was reported to us. This procedure was then repeated for groups formed on the basis of 2003 and 2004 coop status.

The end result is a set of roughly 100 observations on coop status each year during 2002-2004 and average historic per-fisherman catch share during 1995-2001. The mean catch share is 1.01%, indicating that the average fishermen caught about 1 percent of the TAC. This statistic makes sense as there were approximately 100 permit holders at Chignik in each year preceding coop formation. The maximum and minimum catch shares imply that highliners in the fishery caught 2.22% of the TAC and the least successful fishermen caught 0.42%.

We rely on panel data, with each observation representing a fishery-year outcome, to test the effect of the coop on fishery rents, consolidation, and salmon prices at Chignik. The panel data help control for the impacts of region-wide, annual shocks to all Alaskan purse seine salmon fisheries that may have also impacted outcomes at Chignik during the coop years. The panel data set consists of 78 fishery-year observations (n=6 fisheries, t=13 years). The six fisheries are Chignik and the other five purse seine salmon fisheries in Alaska. We focus on thirteen years of data (1997-2009) because this time span affords five years of data before and after the coop was active. Panel A of Table 1 gives summary statistics for the panel data. The dependent variables are the average price of a fishing permit that was permanently transferred to another fisherman, the proportion of licenses owned that are actively fished, and price received by fishermen (from processors) per pound of salmon. Note that we use the sale prices of fishing permits to proxy expected rents from the fishery; permits are permanent rights to compete for a share of each season's TAC.[33] The key independent variable is binary; it takes a value of 1 during the 2002-2004 coop years at Chignik. The other independent variables are fishery-specific fixed effects, year effects, and the total allowable catch (TAC).

To test the predictions on season length and spatial deployment of effort we use annual time-series data from the Chignik fishery rather than panel data. We use time-series data because we were unable to find comparable data on season length and spatial location of harvest for the other purse seine fisheries. For season length, we use annual observations on the number of days fished at Chignik over 1980-2008; these are the years for which we have data. For the coop years, season length gives the number of days fished by either the independent or cooperative fleet; with minor exceptions, these fleets fished on different days. For spatial deployment of effort, we designate Chignik Lagoon (see Fig. 1 and Fig. 2) as the 'inside' location and catches from

[33] The TAC for sockeye salmon in Chignik is exogenous to the institutions governing capture. As with most salmon fisheries in Alaska, the sockeye TAC is set annually to achieve an exogenous pre-determined escapement level (for example see Pappas and Clark, 2003).

elsewhere to be ‘outside’. We examine annual time-series data from Chignik to see how the proportion of sockeye caught ‘inside’ deviated during 2002-2004 from longer time trends during 1973-2008, the entire period limited entry has operated in Alaska fisheries. Panel B of Table 1 gives summary statistics for the time series data. We also examine daily catch data from Chignik during 2002-2004, and compare the location of the catch during days fished by the coop versus the independent fleet.

4.2. Relationship between skill and the decision to join the coop

Our model predicts that highliners will remain independent while less-skilled fishermen will opt into the coop (Prop.3). The model also suggests that an individual’s historic catch share under independent fishing is a good proxy for the critical skill parameter, γ. Accordingly, we test skill-related predictions with the ranked and clustered data on individual catch shares during the pre-coop period.

Panel A of Table 2 shows that the historic catch shares of those who fished independently during 2002-2004 significantly exceeded catch shares of coop joiners (1.29 percent compared to 1.00 percent), which agrees with the theory. Tests for first-order stochastic dominance in the empirical distribution functions provide further corroboration. Panel A of Figure 4 plots cumulative density functions for the historic catch shares of joiners and independents. From visual inspection, the empirical CDF for independents stochastically dominates that for joiners indicating greater skill for the former group. A Kolmogorov-Smirnov test (available from the authors) confirms that the differences in the CDFs are statistically significant. We discuss panel B of Table 2, and panel B of Figure 4 shortly.

4.3. Consolidation, spatial deployment of effort, and public input provision

The model predicts that a profit-maximizing cooperative will consolidate fishing effort among its most skilled members. In order to make maximal use of its most efficient harvesters the coop limits the *number* of members who actually fish, which slows the rate of fishing and lengthens its season. By contrast, all independents are predicted to fish each day their season is open, causing the regulator to shorten their season in order to meet the TAC constraint. Thus, we expect to see the following patterns in the data: a decline in the proportion of permits actually fished at Chignik during 2002-2004, an extension in the number of days fished during this period, and a concentration of fishing effort among the coop’s more efficient members.

We test the first of these predictions by examining the effect of the coop on the proportion of licenses actually fished using the panel data summarized in Table 1. Panel A of

Fig. 5 shows simple and transparent evidence that the coop policy dramatically consolidated the Chignik fishery. The proportion of permits actively fished in Chignik fell from 0.94 in 2001 to 0.41 in 2002 when the coop first operated, and then increased after the coop was effectively dissolved in 2005.[34] The darkest bars show the difference between Chignik and the average across the other purse-seine fisheries. This difference was strictly positive before and after the coop years, but approximately zero during 2002-2004. Panel B of Figure 5 is discussed shortly.

Column 1 of Table 3 shows our estimate of the effect of the coop policy on the proportion of active licenses using the panel regression model in equation (6).

$$\textit{proportion of permits fished}_{it} = \delta_t + \alpha_i + \beta(\textit{coop policy})_{it} + TAC_{it} + u_{it} \qquad (6)$$

Identification of β, the coop policy effect, comes from within-Chignik annual changes in the proportion of permits fished, controlling for annual shocks (δ_t) that could affect the proportion of licenses fished in all purse seine salmon fisheries (for example, fuel prices and the price of farm-raised salmon) and time invariant differences in the proportion fished across the six fisheries (α_i). The model also controls for time-variant differences in salmon runs as reflected in the fishery-specific annual TAC. The result indicates that the coop policy reduced the proportion of permits fished by 0.31. The direction of the effect, a reduction, is consistent with expectations and the coefficient estimate is economically and statistically significant.[35] The result is particularly striking because it pertains to consolidation across the entire fishery, not just within the coop. Consistent with our theory, annual Chignik Area management reports indicate that

[34] The spike up to 0.98 in 2005 is worth explaining. In early 2005, shortly before the start of the fishing season and after the coop was already formed for the 2005 harvest, the Alaska Supreme Court ruled that the coop violated an Alaska law prohibiting permit holders who did not actively fish from accruing profits. The state's remedy for the 2005 season was to allow the coop to fish but to require that all coop members actively fish for a small part of the season. In 2006, the coop was entirely dissolved. We discuss the Court decision in more detail later.

[35] To correct for possible serial correlation of errors within each fishery we conduct a robustness check recommended by Bertrand, Duflo and Mullainathan (2004). We collapse the data into averages for each fishery during three time periods – before, during, and after the coop years. We next run a panel regression using the 18 observations (6 fisheries and 3 time periods) and include fishery and time period fixed effects along with the average fishery-wide TAC. This generates consistent standard error estimates (Bertrand, Duflo and Mullainathan 2004). The resulting coefficient on the coop policy for the collapsed data is of -0.311 with a t-statistic of 4.15.

almost all of the consolidation occurred within the coop; during 2002-2004 the proportion of permits actively fished was 0.25-0.28 for the coop and 0.92-1.0 for independents.[36]

We test the prediction that the coop consolidated effort among its most skilled members by comparing mean historic catch shares for fishing versus non-fishing coop members. The comparison, shown in Panel B of Table 2, indicates that those who fished for the coop had higher historic catch shares than those who did not (1.11 percent compared to 0.90 percent), which agrees with our prediction. Panel B of Figure 4 plots the harvest share cumulative density functions for coop members who fished and coop members who did not fish using the ranked and clustered data described above. From visual inspection, the empirical CDF for coop members who actively fished dominates the CDF for those who did not fish (except for a single exception near the right tail) and a Kolmogorov-Smirnov test (available from the authors) confirms that the difference is statistically significant.

To test the season length prediction we employ time-series data on the annual number of sockeye salmon fishing days at Chignik during 1980-2008 (see Panel B of table 1 for summary statistics). The time-series regression model is shown in equation (7).

$$\begin{aligned} days\ fished_t = \alpha + \beta(coop\ policy)_t + \pi_1 t + \pi_2 t^2 + \pi_3 t^3 + \pi_4 t^4 \\ + \mu_1 TAC_t + \mu_2 TAC_t^2 + \mu_3 TAC_t^3 + \mu_4 TAC_t^4 + u_t \end{aligned} \quad (7)$$

The time-series model accounts for the cyclical nature of the time-series data by including a 4th-order polynomial time trend and controls for variation in harvest by including a 4th-order polynomial in the annual allowed catch. The regression estimate in column 1 of Table 4 indicates that, on average, the presence of the coop lengthened the season by 32 days, a 48 percent increase in season length from the long run average of 67 days in non coop years.[37]

To summarize, the empirics to this point show that the coop consolidated effort among its most efficient members and this consolidation lengthened the fishing season (and presumably lowered costs) as the model predicts. The model further predicts that the coop will coordinate on the *location* of harvest in order to reduce costs. Because the coop secures a guaranteed allocation of catch, coop harvesters should wait until fish migrate inside into Chignik Lagoon, at which time

[36] Members who fished on behalf of the coop were paid salaries to compensate for their costs. All coop members were then paid equal shares of the profit remaining after these salaries and other coop costs were deducted; Knapp and Hill (2003).

[37] The trend variables are included to control for possible non-stationarity in the mean number of days fished. Dickey Fuller and Phillips-Perron tests for unit roots, however, support the assumption of stationarity in the annual data. The test results are available from the authors.

the harvest will be more efficiently executed (Prop. 1.i). In contrast, some or all of the independent sector's harvest is expected to take place 'outside' (Prop. 2.iii). We use data on the spatial location of catch to test these propositions in two different ways. First, we examine fishery-wide annual time-series data to see how the proportion of sockeye caught inside deviated during 2002-2004 from longer annual time trends. We then use within-fishery data on daily catch to assess how the proportion of 'inside' catch differed between coop and independent fishermen during 2002-2004.

Panel B of Figure 5 shows the fishery-wide proportion of sockeye caught 'inside' over an 11 year period that includes 2002-2004, the coop's years of operation, and provides transparent visual evidence that the proportion caught 'inside' peaked during the coop years. We employ a time-series regression model to more rigorously test for the effect of the coop on inside catch. The time-series model is the same as Equation (7) except that now the dependent variable is the proportion of sockeye salmon caught 'inside'. The regression results shown in column 2 of Table 4 indicate that the coop policy increased the proportion caught inside by 0.28.[38] Note that this proportion applies to the entire fishery, including both coop fishermen and independents, and in that sense understates the behavioral change the coop implemented.[39]

Table 5 compares the location choices of coop and independent fleets during 2002-2004 using detailed daily catch data from the 2002-2004 annual Chignik management reports. As the model predicts, the coop harvested its *entire allocation* inside Chignik Lagoon in each year.[40] By comparison, the independent fleet harvested from both inside and outside in 2002 and 2003, which is consistent with the possibility of a mixed equilibrium (prop. 2iii). During 2004 when there were only 13 independents, all independent harvest took place inside the lagoon.

Our evidence on provision of shared or public inputs by the coop is qualitative, gleaned from trade press accounts and annual management reports of the Alaska Department of Fish and

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[38] The trend variables are included to control for possible non-stationarity in the mean of proportion of inside catch. Dickey Fuller and Phillips-Perron tests for unit roots, however, support the assumption of stationarity in the annual data. The test results are available from the authors.

[39] The time-series regression does not control for marine fuel prices, which could influence the decision to fish inside or outside. Data on fuel prices have been collected since 1999 through the Fisheries Economics Data Program (see www.psmfc.org/efin/data/fuel.html#REPORTS). The data show that the mean price of a gallon of fuel in Alaska (in 1999 dollars adjusted for the Anchorage, Alaska CPI) during the summer months of the three coop years was $1.36 and the mean price during the summer months of the seven non-coop years was $2.00. So the proportion of fish caught inside was higher during the coop years despite the relatively low fuel prices that should have otherwise encouraged relatively more outside fishing.

[40] The following account from a coop founder makes clear that fishing inside was a conscious operating policy: "We had originally planned to employ a couple of large … seiners to fish out on the capes [outside], but we realized that the extra running time would increase costs and reduce product quality. Harvesting in the close proximity and concentrated harvest area of the Chignik Lagoon [inside] was simply the most efficient and quality conscious method to pursue." (Ross 2002a).

Game (ADFG). The most prominent shared inputs installed by the coop were 'fixed leads', stationary nets placed along the fish migration route to funnel the stock toward waiting purse seiners.[41] The fixed leads altered the style of fishing and dramatically reduced the number of vessels required to achieve a given catch. This sort of shared infrastructure was not employed by the independent fleet.[42]

Other actions we characterize as public input provision by the coop amount to very precise coordination of members' actions. One important form of coordination was a finely tuned temporal allocation of its members' effort (Stichert, 2007). During low tides Chignik Lagoon, the inside location where the coop harvested, shrinks to a fraction of its size at high water. This concentrates the fish and reduces harvest cost. A prominent coop member described how the coop coordinated effort to exploit this phenomenon:

> "Instead of [a coop member] making four or five sets … during the flood [high tide] for 200 to 300 [fish] a haul, he now could wait till the Lagoon drained out. At low tide … [the channel] became a slow, meandering river of concentrated sockeye. And now, fishing for the entire coop, he could make one giant drag for 3,000 to 5,000 fish."[43]

This strategy required that coop harvesters allow fish to escape up river during high tides, even though it was legal to catch them. Given the coop's secure catch allocation and its ability to coordinate, however, the incentive to do this was present. We know of no instances of independent fishermen intentionally allowing fish to swim up river.

The coop also coordinated its members' actions to improve the quality of fish delivered to processors. It received permits to hold live fish in net pens for up to three days, which allowed it to better match deliveries to processing capacity. On occasion, the coop even released live fish from capture when processing capacity was insufficient.[44] Independent harvesters have no incentive to engage in such practices and we are aware of no evidence indicating that they did. The coop also coordinated information on stock locations from all of its active members and used this information to dispatch vessels and crews to the most advantageous locations. We are aware of no evidence that the independent fleet followed this practice; indeed, fishermen are notorious for hiding such information from their competitors.

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[41] See Pappas and Clark (2003).

[42] Ross (2002a). The use of shared infrastructure was also a hallmark of Native American salmon fishing in the Pacific Northwest prior to commercialization. Certain types of fishing gear required cooperative effort in handling and construction, and ownership of this gear was reportedly shared among individuals and tribes (Higgs 1982).

[43] Ross (December 2002).

[44] The preceding two examples are from: Mark A. Stichert, *2004 Chignik Management Area Annual Management Report*. Alaska Department of Fish and Game, at: http://www.sf.adfg.state.ak.us/FedAidPDFs/fmr07-15.pdf. (2007)

Finally, the coop's ability to coordinate benefitted the fishery manager by enabling precise control of a day's catch. With independent fishing the fishery manager must forecast the rate of catch and announce a closing time calculated to meet the overall catch target, an imprecise process at best. On days the coop fished, the manager could hit the target precisely simply by requesting that the coop cease fishing when the desired number of fish was caught (Pappas and Clark, 2003).

4.4. Salmon prices and license values

In this section we estimate the effect of the coop policy on ex-vessel salmon prices and on license values. These outcomes are related to our theoretical model but not explicitly addressed by it. For example, the model does not predict higher ex-vessel prices, but it does provide a rationale for why prices paid to fishermen should be higher under the coop regime. The rationale is that the consolidation and coordination induced by the coop should naturally lead to higher quality fish being delivered to processors and a price premium for coop fishermen.[45] Indeed, the possibility of exercising greater care in harvesting in order to deliver a higher quality product was prominent in initial discussions on forming a coop. Additionally, the coop may command a higher price due to having greater leverage in negotiating prices with the small number of fish processors operating at Chignik. It is widely believed that processors extract most of the rents from negotiation with independent fishermen; presumably, a coordinated harvester group could wield its own market power. Both considerations indicate that the coop's formation might lead to higher prices to coop fishermen.[46]

We cannot separate these two effects empirically, but we can test for a price increase with the panel-regression format in Equation (6), using the ex-vessel price per pound of salmon as the dependent variable. The regression results (column 2 of table 3) indicate that formation of the coop was accompanied by an average price increase of \$0.24 per pound in the Chignik fishery (in 2009 dollars). This represents a 32 percent increase from the Chignik average of \$0.75 outside of

[45] There is strong evidence for longer seasons, higher quality, and higher value product in fisheries with secure catch allocations. Concrete data from Alaskan halibut, New Zealand snapper, and Australian bluefin tuna show an increase in quality and ex-vessel value (Leal 2004). Emerging qualitative evidence from newly formed individual fishing quota fisheries on the west and east coasts of the United States show similar outcomes.

[46] We chose not to incorporate the market power feature explicitly in the model in part because its effect seems obvious and in part because this seems specific to Chignik. The coop's incentive to coordinate to guarantee higher product quality is similar to its incentive to provide club goods, and in that sense is consistent with our model. The difference is that enhanced product quality raises price, while we treat the effect of club goods as decreasing costs.

the coop years during 1997-2009. [47] Note that this is a lower-bound estimate of any price premium the coop achieved because nearly one-third of the sockeye caught at Chignik were harvested by independents during 2002-2004.[48]

The evidence thus far indicates that the coop policy lowered fishing costs and raised ex-vessel prices suggesting that the policy also increased profits. We lack data on individual firm-level profits, but we do have data on the value of fishing permits. The value of a Chignik fishing permit should reflect the expected present value profit that a marginal (low skill) fisherman could earn in this fishery. The marginal fisherman's profit is relevant, rather than the highliner's profit, because (ignoring differences in non-pecuniary returns) the marginal fisherman would have the lowest reservation price for selling a permit and would therefore determine the transaction price to potential buyers.

Column 3 of table 3 shows our estimate of the effect of the coop policy on permit value using the panel-regression format in Equation (6). The result indicates that the coop policy increased the value of a permit by $59,130 in 2009 dollars. This implies that the option to join a voluntary coop substantially increased the amount that buyers would pay for a permanent right to fish at Chignik. This is a 32.6 percent increase relative to $181,004, which was the mean value of a Chignik permit over 1997 to 2009 excluding the coop years.[49]

The permit value difference presumably reflects the coop's effect on the present value of expected future annual profits, but the implied annual profit effect is complicated because the coop's life span was unknown. We deal with this uncertainty by estimating a range of values for the implied annual profit effect, each based on a different assumption about the coop's expected life span. The lawsuit that eventually ended the coop was filed in April 2002 (*Grunert v. State* 2005, p. 928), just before its first year of operation. We therefore set the lower bound life expectancy at 3 years, its actual period of operation. We set the upper bound at infinity, corresponding to an expectation that it would persist in perpetuity. To calculate the profit effect,

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[47] The price data are inflation adjusted and are in 2009 dollars. As before we estimated a version of the regression in Table 10 by collapsing the data into averages for each fishery during three time periods – before the coop years, during the coop years, and after the coop years. This approach generates consistent standard error estimates (Bertrand, Duflo and Mullainathan 2004). The resulting coefficient on the Coop Policy for the collapsed data is 0.238 with a t-statistic of 2.66.

[48] We lack cross-section data during 2002-2004 that would allow us to compare output prices between the coop and independent sectors.

[49] As before we estimated a version of the regression in column 3 of table 3 by collapsing the data into averages for each fishery during three time periods – before the coop years, during the coop years, and after the coop years. This approach generates consistent standard error estimates (Bertrand, Duflo and Mullainathan 2004). The resulting coefficient on the Coop Policy for the collapsed data is 59,115 with a t-statistic of 1.46.

let π indicate the expected annual profit before the coop formed, and assume it is constant; let V indicate the pre-coop license value and let r be the interest rate. Assuming license values observed before the coop formed did not incorporate expected profits from the coop's possible formation, the preceding variables are linked by $V = \pi / r$. Let ΔV be the change in license value resulting from the coop's formation, which we estimate, and let T indicate the number of years the coop was expected to operate. We wish to estimate the proportionate change in profit resulting from allowing the coop to form, Φ. The appropriate present value formula gives $\Delta V = \{\Phi\pi / r\} \cdot \{1 - 1/(1+r)^{T+1}\}$. The term of interest, Φ, can now be found by combining the two preceding expressions: $\Phi = \Delta V / V \cdot \{1 - 1/(1+r)^{T+1}\}^{-1}$.

Applying this formula to the data yields the results in table 6. The lower-bound estimate of the annual gain in the marginal fisherman's profit due to the coop's formation is 33 percent. If parties bidding for Chignik licenses thought the coop would last for 5 years, the implied proportionate effect on the marginal fisherman's annual profit is a 75 to 98 percent increase and other entries in table 6 have similar interpretations. This profit gain includes both an efficiency component resulting from the coop's fishing policy and a component that results from the low skill member's opportunity to share profits with more efficient coop joiners.

4.5. Stability of the coop

Our empirical evidence on the question of coop stability and Pareto improvements consists of data on the historic catch of coop joiners and independents, the regulator's TAC allocation rule and the lawsuit that challenged the coop. Our model (Prop. 4i) indicates that dividing the TAC between the coop and independent sectors in proportion to aggregate skill, corresponding to $\theta = \theta_c$, would make those who choose to join the coop better off and leave those who choose to fish as independents indifferent. This is a 'knife-edge' Pareto improvement, however; even a slight deviation from this TAC division that disfavors the independents ($\theta > \theta_c$) would make all independents worse off and presumably cause them to oppose the coop's formation.

The allocation rule set forth when the coop was first authorized (described in section 2) resulted in a TAC share for the coop of 0.693 in 2002, its first year of operation. This share resulted from having 77 joiners and a nine-tenths per capita share ($\theta = 0.9$) for each ($77 \times 0.9 = .693$). The coop's assigned catch share was within 1 percentage point of the aggregate historic catch share of fishermen who chose to join the coop and the outcome in 2003 was essentially identical. Using historic pre-coop catch share as a measure of skill (as we argue is appropriate), our model implies that the 2002-2003 allocation was right on the knife's edge for a Pareto improvement, that is, it was set almost exactly at our critical value, θ_c. Any deviation that worked against independents would create a situation in which all independents would gain if the coop was abolished.

In 2004 the coop's membership increased 87. To ensure a Pareto improving outcome as the size of the independent fleet declined, the TAC allocation granted for each independent permit holder would need to be increased (in other words θ would need to decline). This is true because those leaving the independent sector to sign on with the coop would be the least skilled independents (Prop. 3), while those continuing to fish independently would be the most skilled. The allocation formula put in place by the regulators did just the opposite. Once coop membership reached 85 in 2004 the allocation rule *reduced* the independent sector's TAC share to coincide with the proportion of permit holders that chose to fish independently. This corresponds to an allocation based on $\theta = 1$, which our model suggests will disadvantage all independents. Rough calculations indicate that it would have been necessary to increase the independent sector's per capita TAC allocation by at least 10% to ensure a Pareto improvement; instead it was reduced by 40%.

The lawsuit challenging the coop policy was filed by Michael Grunert and Dean Anderson. Consistent with the model's predictions, both were among the highest earning Chignik permit holders and neither joined the coop. The fact that Grunert and Anderson filed the lawsuit in 2002 suggests that they assigned a positive probability to the number of joiners growing over time to the point where highliners would become disadvantaged by the TAC allocation rule, which clearly seems to be what happened by 2004.

All those who participated in the Chignik fishery during the coop years, joiners and independents alike, seemed to agree that coordinated fishing as practiced by the coop could yield substantial efficiency gains both from reduced harvest costs and enhanced catch quality. As noted earlier, experience with coordinated fishing at Chignik during two strikes against processors in 1991 and 2001 left no doubt that strategies such as keeping some vessels idle, concentrating effort near processing facilities and using stationary nets to guide salmon toward awaiting purse seiners would pay off (Knapp 2007). Even Dean Anderson, one of the two highliners who filed the suit that ended the coop, argued (shortly after filing the suit) in favor of organizing all effort in the fishery through harvester cooperatives in order to raise efficiency (Anderson 2002).

The key to the coop's demise, therefore, was not disagreement or uncertainty over efficiency effects. Rather, the problem was disagreement over dividing the fishery's rents. This problem took two forms: conflicts over how the coop and independent sectors should share the

TAC; and disagreements over how the coop should divide profits among its members. Controversy over the between-sector TAC division plagued discussions of prospects for forming a cooperative at least as far back as 1997 (McCallum 1997) and continued up to the time the coop was authorized. Disagreements on how coop profits should be divided among members were voiced in early discussions among the coop's founders. While alternative sharing proposals were considered, these negotiations proved difficult and in the end a simple equal division rule was adopted. Our model, which treats historic catch share as a proxy for fishing skill, suggests a way to soften these disagreements: make both the between-sector TAC division and coop members' profit shares proportional to historic catch shares. This would ensure that all permit holders could gain if the coop formed; it also ensures that all would earn higher profit from joining the coop than from fishing independently. While this rule might not end the debate over rent shares, one piece of evidence suggests that it could have lowered the volume: *the* key component of Dean Anderson's (2002) proposal for managing salmon harvests entirely through cooperatives was to base the distribution of profits on historic catch shares.

5. Conclusions

The state's prominent role in managing shared natural resources stems from the difficulty of establishing property rights for assets such as stocks of fish, subsurface reservoirs of water and oil, and clean air. Stylized treatments of the management problem often recommend price or quantity instruments that mimic the outcomes markets for these assets would achieve if property rights were well defined. These solutions often prove difficult to implement, however, and their performance in practice is sometimes disappointing. This is not entirely surprising. The theoretical treatments that prescribe these solutions often rely on top-down intervention by a benevolent government, often only implicit in the analysis, to observe what needs to be observed and to make wise choices. A different approach is gaining favor in recent years, assigning rights to certain aspects of resource use and then relying on rights holders' incentives to solve detailed management problems.

Despite evidence of potential gains from management reforms based on assigning rights, progress in this direction has been relatively slow. Less than two percent of the world's fisheries currently employ the most prominent rights-based regime, the individual catch share, and pollution control based on assigning quantitative emission rights to individual polluters remains relatively rare. One key holdup is at the stage in which the initial allocation of rights is assigned, a process that invariably invites rent-seeking contention. A second is that, without additional contracting, individually held rights will not capture gains from coordinating the actions of different users.[50] The short lived experiment with a self-selected cooperative in the Chignik, Alaska sockeye salmon fishery, with its voluntary membership and group-held harvest rights, offers valuable lessons on both counts.

First, coop membership was voluntary and the task of devising an acceptable division of the coop's allocation (or the resulting rents) among members was internalized within this self-selected group. This arguably reduced the initial allocation problem by taking the difficult task of assigning shares to individuals out of the regulatory arena, where political power and lobbying could have amplified transactions costs. The regulator's only role was to make the gross division of catch between sectors. Sullivan (2000) reports evidence from the Pacific whiting and Alaska pollock cooperatives that this structure can ease the quota assignment problem. Once the catch shares for these cooperatives were determined by the regulator, the groups internally negotiated sharing arrangements among members in a matter of a few hours to a few weeks.

Second, rights were assigned to a group rather than to individual harvesters. This made it easier for the rights-holding sector to coordinate actions of its individual members. The coop achieved coordination by adopting bylaws that required all joiners to sign a contract before the start of a season that placed their fishing effort under the direction of a manager. The manager was responsible to a board of directors, elected by the members, and charged with promoting the interests of the membership. This contractual structure is not fundamentally different from that of a worker-owned corporation. In Chignik, coordination substantially increased rents, making the shift away from the old race-to-fish regime a more lucrative positive sum game than it otherwise would have been. While individual rights holders could in principle achieve the same coordination gains by contracting with one another, the transaction costs would plausibly be prohibitive.[51]

Our theoretical analysis of behavioral and distributional effects of a self-selected fishery cooperative corroborates the economists' intuition that assigning property rights can reduce costs,

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[50] Coordination can improve on the use of shared resources whenever ownership is determined by the rule of capture, for example ground water, oil and gas, but achieving this outcome contractually can be difficult. In the U.S., oil is nominally owned by land owners with property above reservoirs and gains from coordination can in principle be captured by unitization agreements. As Libecap and Wiggins (1984) document, however, the transactions costs involved in forming such agreements are most often prohibitive.

[51] Allocating dedicated catch shares to harvester groups to manage (within broad constraints) is a growing trend in fishery management. Recently formed sector allocations for groundfish in New England and coop allocations for Alaska pollock and Pacific whiting are prominent U.S. examples. The reasons cited for this trend include the relative political ease of assigning rights among a few sectors rather than scores of individual users and the gains from coordinating effort.

enhance efficiency of capture, and ultimately increase rents. We were also able to empirically verify these predictions using a mix of time series, cross sectional and qualitative data. These results provide guidance on the management of fisheries, where lessons from the Chignik experience suggest that reforms enabling self-selected cooperatives can be Pareto improving, provided that they are designed with care. But the Chignik lessons may also inform the management of mobile natural resources more broadly. During this age of global transition from regulated open access to forms of property rights, policies that encourage cooperative extraction should provide economic benefits not easily captured by individual rights allocations.

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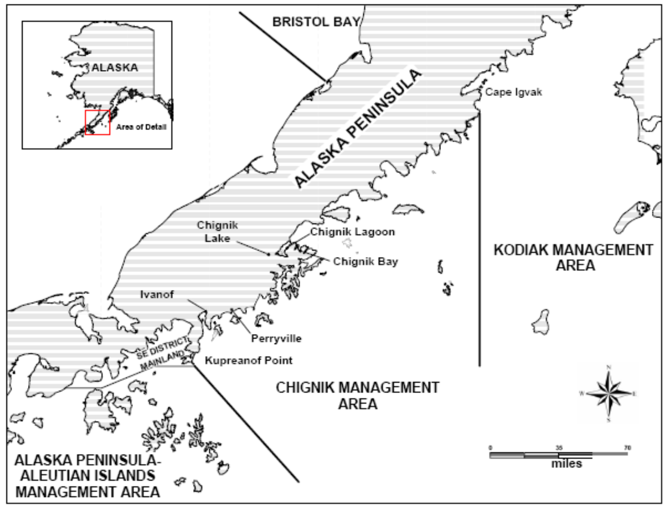

Fig. 1.

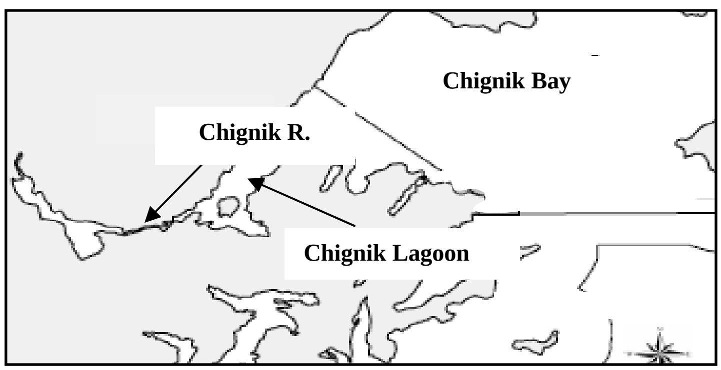

Fig. 2.

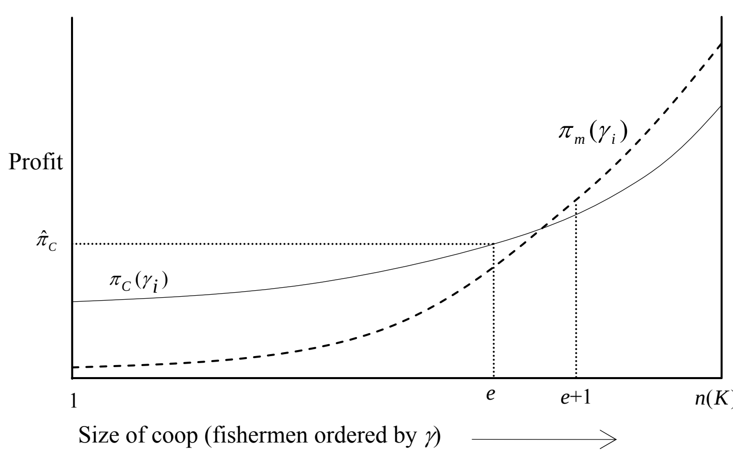

Fig. 3

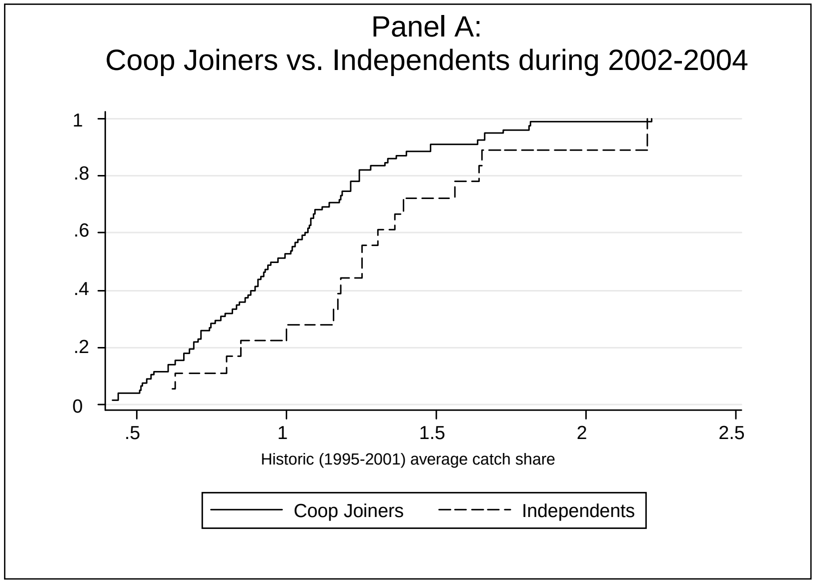

Figure 4, panel A

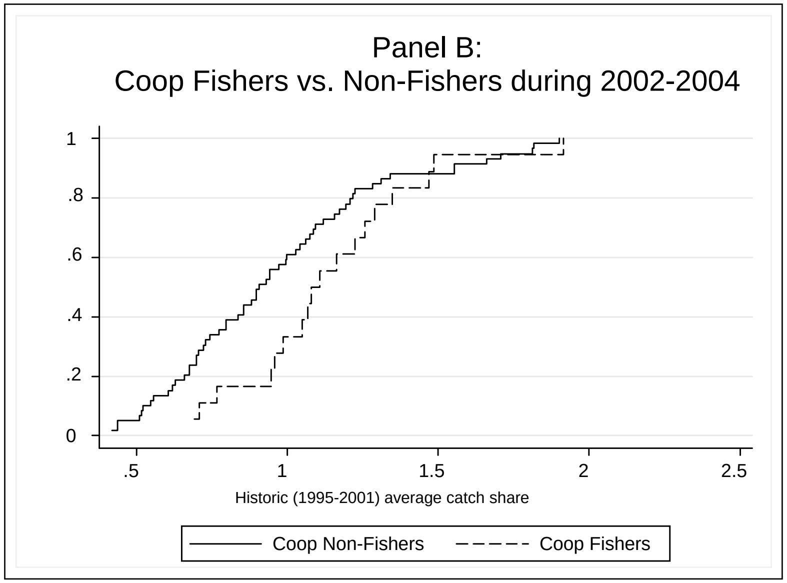

Figure 4, panel B

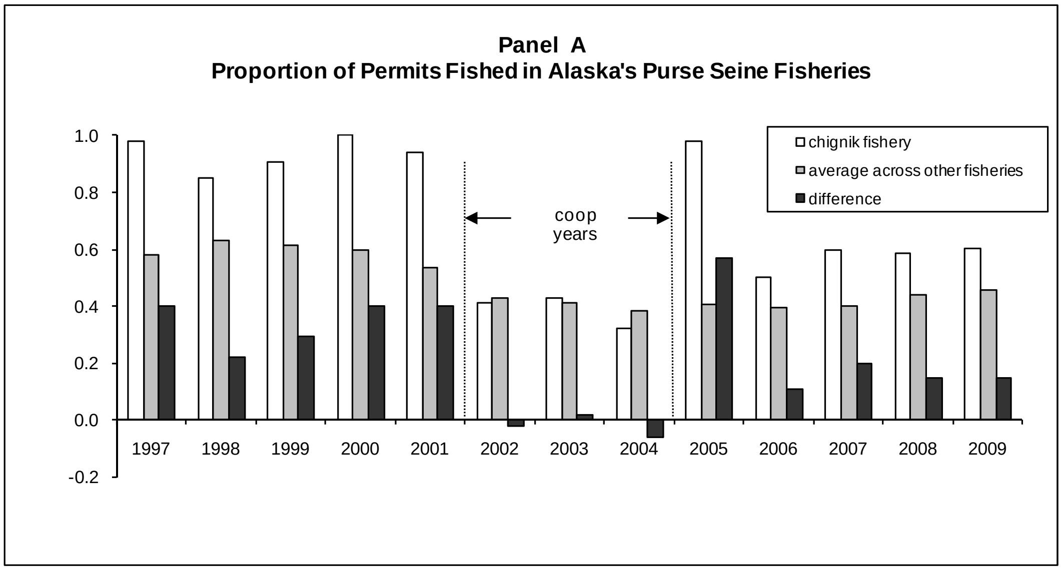

Figure 5 Panel A.

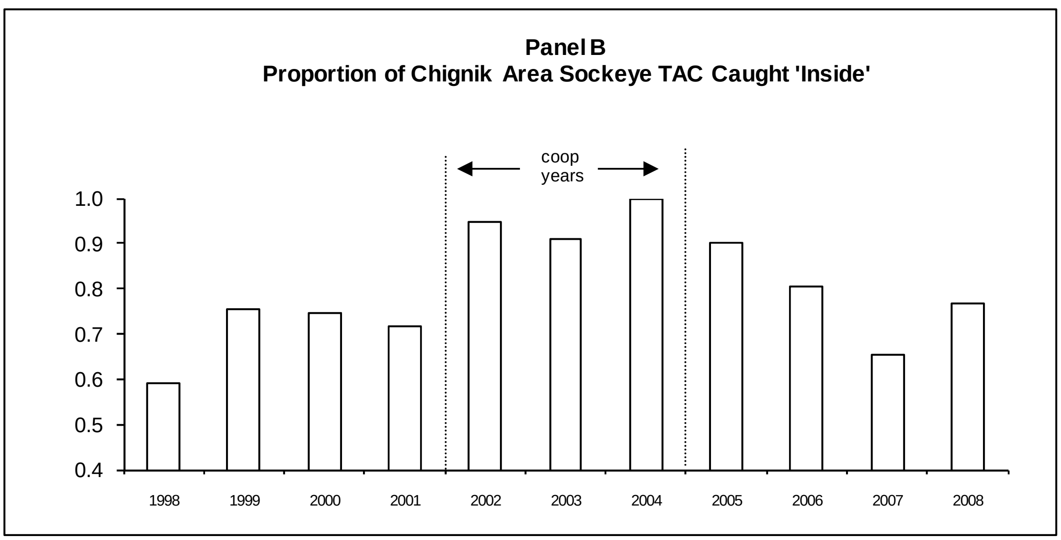

Figure 5 Panel B.

Figure legends

Fig. 1. Chignik Management Area on the Alaskan Peninsula

Source: Stichert (2007).

Fig. 2. Chignik Lagoon and Near Vicinities

Source: Stichert (2007).

Fig. 3. Equilibrium coop size

Figure 4 panel A

Cumulative Density Functions of 1995-2001 Average Catch Shares

Figure 4 panel B

Cumulative Density Functions of 1995-2001 Average Catch Shares

Figure 5 Panel A. Comparisons of Permits Fished and Inside Catch

Panel A notes: The mean differences for the three time periods are as follows: 0.34 for 1997-2001, -0.02 for 2002-2004, and 0.23 for 2005-2009.

Figure 5 Panel B. Comparisons of Inside Catch

Panel B notes: The means for the three time periods are as follows: 0.70 for 1998-2001, 0.95 for 2002-2004, and 0.78 for 2005-2008.

Table 1.

Summary Statistics of the Panel and Time Series Data

	Obs.	Mean	St. Deviation	Minimum	Maximum
Panel A: Panel Data					
Dependent Variables					
Average Permit Price (2009 $s)	78	65,823	69,304	10,062	252,510
Proportion of Permits Actively Fished	78	0.519	0.194	0.159	1.000
Price Per Pound (2009 $s)	78	0.397	0.25	0.126	1.095
Independent Variables					
Coop Policy (=1 if in place, otherwise 0)	78	0.038	0.193	0.000	1.000
Fishery-Wide TAC (lbs of salmon, 000s)	78	66,336	69,612	1,619	295,817
Panel B: Time-Series Data					
Dependent Variables					
Number of Days Fished	28	68.89	11.60	50.0	102.0
Proportion Caught 'Inside'	36	0.787	0.151	0.450	1.000
Independent Variables					
Coop Policy (=1 if in place, otherwise 0)	36	0.083	0.280	0.000	1.000
Fishery-Wide TAC (# of Sockeye, 000s)	36	1,381	593.4	399.6	3,116

Panel A Note: There are 78 fishery-year observations with i=6 fisheries and t=13 years. The six purse seine fisheries are: Alaska Peninsula, Chignik, Cook Inlet, Kodiak, Prince William Sound, and Southeast. The years are 1997-2009. The data come from the fishery participation and earnings statistics of the Alaska Commercial Fisheries Entry Commission. The data can be downloaded at: www.cfec.state.ak.us/fishery_statistics/earnings.htm.

Panel B Note: The data summarize 36 years of Chignik fishery data for Proportion Caught Inside, Coop Policy, and Fishery-Wide TAC (1973-2008). The table summarizes 28 years of data for Number of Days Fished (1980 – 2008). The data come from Annual Chignik Management Reports for 2002-2008, published by the Alaska Commercial Fisheries Entry Commission.

Table 2

Comparison of Mean Catch Histories for Ranked and Sorted Clusters of Fishermen

	# of Obs.	*Mean Catch Share*	*Standard Deviation*	*t-stat for diff. in abs. value*
Panel A: Independents v. Coop Joiners				
Independents	18	1.29	0.0036	2.90**
All coop members	78	1.00	0.0045	
Panel B: Coop Fishermen v. Non-Fishermen				
Coop members who fished	18	1.11	0.0030	1.83*
Coop members who did not fish	59	0.90	0.0036	

Notes: * Significant at 0.05 level for a one-tailed t-test with equal variance, ** significant at 0.01 level for a one-tailed test with equal variance. Allowing for unequal variance, the t-statistic for the panel A comparison is 2.53 and the t-statistic for the panel B comparison is 2.02. The data used here are pooled for 2002-2004.

Table 3

Panel Regressions of Permits Fished, Ex-Vessel Prices, and Permit Values

	(1)	*(2)*	*(3)*
Independent Variables	*Y = proportion of permits fished*	*Y = price per pound*	*Y = permit value*
Constant	0.441**	0.581**	69,028**
Coop Policy	-0.311**	0.238**	59,130*
Fishery-Wide TAC	3.79e-08	-1.25e-06*	-0.093
Fixed Effects			
Year Dummies	Included	Included	Included
Fishery Dummies	Included	Included	Included
Observations	78	78	78
Adjusted R^2	0.855	0.818	0.820

Note: * Significant at 0.05 level for a one-tailed t-test, ** significant at 0.01 level for a one-tailed test. The permit value data are adjusted by the CPI and are presented in 2009 dollars. The 5 control fisheries are the other purse seine fisheries: Alaska Peninsula, Cook Inlet, Kodiak, Prince William Sound, and Southeast, and the year dummies span 1997-2009. The omitted observation is the Cook Inlet fishery during 1997. Summary statistics are provided in Panel A of Table 1.

Table 4

Time-Series Regressions of Season Length and Inside Catch

Independent Variables	*(1)* *Y = number of days fished*	*(2)* *Y = proportion of catch from inside*
Constant	509.7*	0.994*
Coop Policy	32.15**	0.284**
Fishery-Wide TAC	0.4006	-1.03e-06
Fishery-Wide TAC ^{2}	-3.17e-10	1.45e-12
Fishery-Wide TAC ^{3}	1.04e-16	-7.47e-19
Fishery-Wide TAC ^{4}	-1.19e-23	1.23e-25
Year	-114.65*	0.045
Year ^{2}	7.649*	-0.004
Year ^{3}	-0.217*	0.0001
Year ^{4}	0.002*	-5.86e-07
Observations	28	36
Adjusted R^2	0.533	0.642

Note: * Significant at 0.05 level for a one-tailed t-test, ** significant at 0.01 level for a one-tailed test. The data come from Chignik area annual management reports and are summarized in Panel B of Table 2. We lack data on season length prior to 1980, so the data for column 1 span 1980-2008. The data for column 2 span 1973-2008.

Table 5

Proportion of Sockeye Caught Inside by the Coop and Independent Fleets

(on days reserved exclusively for one of the two fleets)

	Cooperative fleet	Independent fleet
2002		
Number of sockeye harvested	576,757	162,979
2003		
Number of sockeye harvested	757,974	334,330
2004		
Number of sockeye harvested	541,400	61,446

Note: The data come from 2002-2004 Chignik annual management reports. In a few instances, each fleet fished on the same day, but at different times. Because the data on spatial catch is reported on a daily basis, we restrict the comparison to those days reserved exclusively for one of the two fleets.

Table 6

Proportionate Profit Increase from Allowing Coop to Form

Increase in license value	$59,130			
Baseline license value	$181,004			
Coop operating horizon (years)	3	5	10	∞
Proportionate profit gain (Φ) (r=.10)	1.03	0.75	0.50	0.33
Proportionate profit gain (Φ) (r=.07)	1.38	0.98	0.62	0.33